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Reconciling organic residue analysis, faunal, archaeobotanical and historical records: diet and the medieval peasant at West Cotton, Raunds, Northamptonshire

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‘I have no penny’, quoth Piers, ‘pullets for to buy,
Nor neither geese nor pigs, but two green cheeses,
A few curds and cream, and an oaten cake,
And two loaves of beans and bran, baked for my youngsters.
And yet I say, by my soul, I have no salt bacon;
Nor no hen’s eggs, by Christ, collops for to make.
But I have parsley and leeks, with many cabbages,
And a cow and a calf, a cart-mare also’.

From Piers Plowman by William Langland c. 1370-90

Declarations of interest: none

Abstract

Information on medieval diet and subsistence practices has traditionally been compiled from a combination of documentary sources, faunal and archaeobotanical assemblages, together with other information gained from archaeological excavations. Much is known of high status medieval dietary practices but less about what foodstuffs the medieval peasantry consumed. Here, we examine the everyday dietary practices of people living in a small medieval manor and associated hamlet at West Cotton, Raunds, Northamptonshire. For the first time, a combined molecular and isotopic approach on absorbed residues, from the substantial pottery assemblage covering a period of around 500 years, was utilised to integrate information on the commodities processed in the vessels, together with detail from the faunal assemblage, archaeobotanical, archaeological and documentary information relating to the site. Lipid residue results from the pottery, mainly jars, identified the importance of ruminant carcass products and leafy vegetables, likely used to prepare the stews or potages known to be the mainstay of the medieval diet, and confirmed by the dominance of sheep and cattle in the faunal assemblage. Around one quarter of the vessels were used to process solely dairy products and some evidence of porcine product processing was found, although this may be under-represented at the site. In brief, this project provided a unique opportunity to address questions of diet and animal husbandry by medieval peasants and helped illustrate agricultural production and consumption in the middle ages.

1. Introduction

Food and diet are central to understanding daily life in the medieval period. Traditionally, information regarding diet and subsistence practices during the medieval period has been obtained from a combination of documentary sources, faunal and archaeobotanical assemblages and other information gained from archaeological excavations. However, each of these sources may have limitations, for instance, documentary sources often provide many details on high status diet but are more limited in the information that they provide on the everyday consumption of food and drink by the medieval peasant.

In the last decades, large-scale excavations at the late Saxon to medieval deserted hamlet of West Cotton, Raunds, Northamptonshire, provided a substantial pottery assemblage covering a period of around 500 years. Significantly, this was not a high-status site, thereby providing an opportunity to examine the everyday dietary practices of people living in a small medieval manor and associated hamlet. Furthermore, there has been little examination of the *direct* role of pottery for processing food during this period, thus, a selection of Saxon and medieval pottery, comprising different vessel types across the chronology of the site, was examined using molecular and isotopic techniques. This multi-faceted study provides a unique opportunity to incorporate information on the commodities processed in the vessels together with detail from the faunal assemblage, archaeological and documentary information relating to the site, to gain an understanding of the peasant diet and agricultural production, consumption and economic life in an early medieval village.

1.1 The West Cotton project

The Raunds Area Project, a joint venture between Northamptonshire County Council and English Heritage, was a major landscape project investigating the process of village formation and development in middle England. The project area encompassed four medieval parishes, Raunds, Ringstead, Hargrave and Stanwick, set within 40sq km of the Nene Valley in Northamptonshire (Chapman, 2010). It comprised extensive large-scale rescue excavations, carried out between 1985 and 1989, together with widespread field survey, detailed documentary studies and archaeo-environmental investigations. The first phase of excavation, between 1977 and 1982, had involved the excavation of an early manorial centre along with its associated church and cemetery at Furnells, Raunds (Boddington, 1996; Audouy and Chapman, 2009).



Fig. 1 Location plan of West Cotton within the local topography

The second phase of the project, carried out between 1985 and 1989, included investigation of the late Saxon to medieval deserted hamlet of West Cotton, Raunds, located on a slightly raised gravel peninsula at the edge of the floodplain in the Nene Valley (Fig. 1). West Cotton is one of three deserted medieval settlements, together with Malloes Cotton and Mill Cotton. There are three phases of settlement at West Cotton, the first being a Saxon settlement covering the period AD 950 to 1100 (Phase 1). This was followed by an early medieval manor and settlement, dating between *c.* AD 1100 and 1250 (Phase 2). Finally, during the period AD 1250 to 1450, the area comprised a medieval manor and hamlet (Phase 3, Fig. 2). It should be noted that the complex sequence of the development of West Cotton occurs within the political context of the reconquest of eastern England by the Saxon kings and the subsequent reorganisation of settlement and society within the Danelaw.

The origins of the planned settlement at West Cotton lie in the mid tenth-century and comprise a late Saxon timber hall with ancillary buildings, and an associated watermill, set within regular one-acre plots. A second similar holding, with dependent peasants, was likely nearby. In the early twelfth century, this was directly replaced by a small stone-built Norman manor house with a two-storey hall, dovecote and detached kitchen/bakehouse and garderobe. Subsequently, the watermill was abandoned at the end of the twelfth century, resulting from a disruption in the water supply, caused by a period of intense flooding and alluviation. The thirteenth century was marked by a reorientation of the economic base, with an emphasis on crop storage and processing. By the mid-thirteenth century, the manor was relocated to the east with peasant

tenements (Figs. 2 and 3) replacing the old manor house, marking the end of direct farming of the manorial demesne. The site then became a full peasant hamlet as the new manor was converted to tenements, although these were progressively deserted through the fourteenth century, and by the mid-fifteenth century the settlement was abandoned and given over to pasture closes (Chapman, 2010).

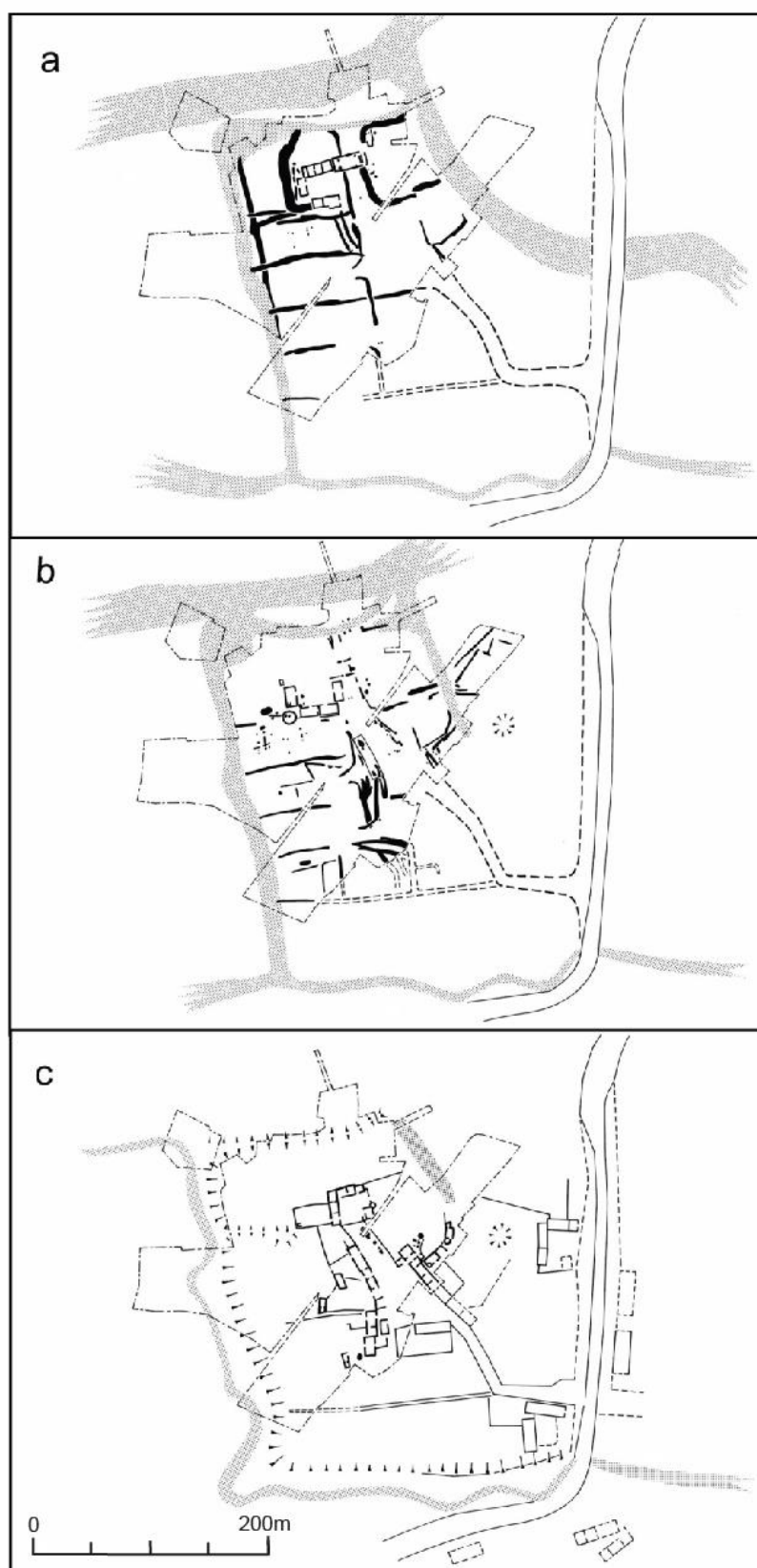


Fig. 2 Site phase plans showing the development from late Saxon to medieval: a. late Saxon phase (950-1100) with its grid of boundary ditches and timber buildings, b. post-Conquest

phase (1100-1250) with some drift of the boundary ditches, encroaching on the central space, and the 12th century manor with its stone buildings, c. the medieval hamlet phase (1250-1450), with the series of stone built tenements, and to the east the barn, kitchen and malt house of the relocated manor (excavated) and presumed new manor house to the east beside the Cotton Lane (not excavated) converted to further tenements around 1300



Fig. 3 Excavation of medieval tenement E dated 1250-1450

1.2 The West Cotton pottery assemblage

The excavations at West Cotton produced the largest Anglo-Saxon and medieval ceramic assemblage from a rural context in Northamptonshire. Of the 107643 sherds of pottery (823.5kg) recovered from the settlement, the majority were late Saxon or medieval in date. The main late Saxon ware was St Neots type, with Cotswolds-type Oolitic wares and Stamford ware making up the rest of the assemblage. St Neots-type ware was also found in later deposits, up to twelfth-century contexts. The vast majority of the pottery from medieval contexts was unglazed, shell-tempered coarsewares (seen as a continuation of the St Neots-type ware tradition) from various local sources, with Lyveden/Stanton glazed wares, Potterspury wares and Brill/Boarstal types making up the bulk of the glazed material (Blinkhorn, 2010). The vessels were generally undecorated and the range of vessel types which occur at West Cotton was very limited, with only jars, bowls, pitchers and (rare) Top Hat vessels occurring (Fig. 4). It should be noted that jars are by far the most dominant vessel, comprising at least three-quarters of the assemblage in each medieval phase (Fig. 5). These took two main forms, a

slightly baggy type, with almost vertical body walls and a rim diameter narrower than that of the base, and a more elegant shouldered variety, with a rim diameter generally larger than the base diameter. The next most common vessel was the bowl, which also came in two main forms, a wide shallow pan with near-vertical sides and a deeper version with splayed sides. Three rare St Neots ware socketed bowls were also found. Pitchers came in a variety of shapes and sizes although they were not common. Interestingly, the pottery assemblage does not show any typological development, being remarkably consistent in form throughout the medieval period.

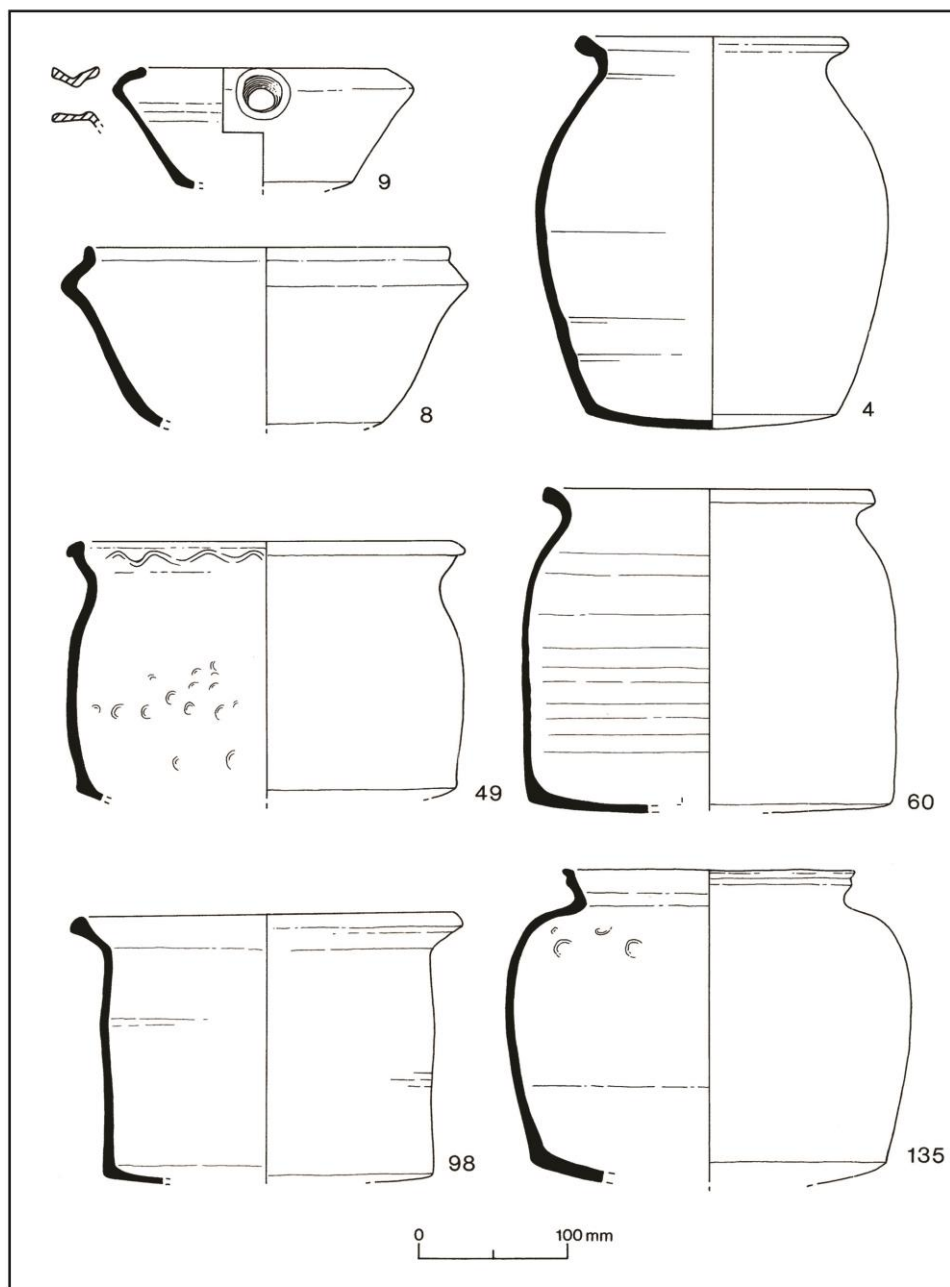


Fig. 4 Representative bowls and jars from West Cotton:

- 9 St Neots-type ware socketed or spouted bowl. Outer body is completely blackened except for the top of the rim and the upper half of the spout. Patches of blackening on the inner surface of the vessel.
- 8 St Neots-type ware inturned rim bowl, with totally blackened outer surface.
- 4 St Neots-type ware jar, with black surfaces. Base pad is slightly scorched internally and externally.
- 49 Saxo-Norman Cotswold-type oolitic jar, with the outer surface progressively more blackened from the shoulder to the base, with patches of sooting.
- 60 Shelly coarseware jar, the outer surface is extensively blackened, with a scorched red outer base pad.
- 98 Shelly coarseware “top hat” jar, with smoke blackened lower body and base.
- 135 Lyveden A ware jar, with the lower body and base quite evenly blackened.

Note: catalogue numbers as in original report (Blinkhorn 2010)



Fig. 5 Typical Shelly coarseware jar (reconstructed)

2. The medieval diet

Much information about the medieval diet is known, generally through the examination of written historical sources such as domestic records (account books), legal, literary or religious texts, chronicles, household, hospital or municipal accounts (Hammond, 1993; Dyer, 1994; Scully, 1995; Dyer, 1998a; Woolgar, 2010). Unfortunately, the majority of cookbooks that survive come from the end of the medieval period, from the fourteenth and fifteenth century, and therefore tell us little about the early Middle Ages. Indeed, the earliest surviving English recipe books date from about 1390 when the *Forme of Cury* was written by order of King Richard II (Black 1985). However, these were compiled and used by the nobility and upper echelons of society and ecclesiastical institutions, thus bearing little or no resemblance to the diet of the poor and lower classes.

Various historical documents attest that the medieval peasant ate meat, fish, dairy products, fruit and vegetables. For example, detailed inventories of peasants' possessions and tax assessments often include the bacon and salt meat stored in the house (Harvey, 1976; Dyer, 1998a). Dairy products, such as cheese, sometimes referred to as 'white meats' of the poor, are thought to have been mainstays of the medieval peasants diet (Adamson, 2004). The size of peasants' garden plots is recorded in documents and has been attested from the archaeological remains of deserted villages. Neither these nor the tithe records for garden plots suggest these were very large or productive, however, these would likely have been a useful asset for peasant families, with garden produce being an important part of their diet (Dyer, 1994). The aristocracy were suspicious of raw greenstuffs – regarding them as unhealthy, and fruit and fresh vegetables, such as garlic, onion and leek, as being 'poor men's food' or as suitable for those doing penance (Dyer, 1994). However, these were consumed by the higher social classes as part of the ascetic diet at Lent.

Cereal foods, often oats or barley, are very important in the peasant' diet with cereal and vegetable pottage being the mainstay of the popular peasant diet. For instance, records from Worcestershire Cathedral Library show that half of the food payments (by value) of harvest workers from the north Worcestershire manor of Bromsgrove in 1321-22 comprised bread and oatmeal, ale accounted for another 28%, with meat, fish and dairy making up the remainder (Dyer, 1998a). Both oats and barley were grown as crops at West Cotton from the Late Saxon period onward, assemblages from ditch system 19 and from the latest mill both produced substantial numbers of oat grains, none of which showed signs of germination. At least in the

former case, the grain seems to have been accidentally burnt during drying prior to grinding. This suggests that some oats were probably grown for pottage grain or oatmeal (Campbell and Robinson, 2010). The use of oats for human consumption has also been suggested for other sites in the south Midlands (Moffett, 1988).

3. The West Cotton faunal assemblage

The West Cotton faunal assemblage is of particular importance as collections of animal bones from rural medieval sites are generally rare, compared to more abundant assemblages from urban or castle sites. Thus, the assemblage provided valuable information in determining the animal products people were eating at West Cotton, butchery techniques, methods of food preparation and rubbish disposal on the settlement. The study also investigated what animal products besides meat were being exploited together with an analysis of animal husbandry techniques (Albarella and Davis, 2010).

Although faunal material from the Early-middle Saxon period (AD 950-1100) was present, it was not a sufficiently large assemblage to allow a full zoo-archaeological study. In contrast to this, large faunal assemblages, covering two periods called *the medieval manor AD 1100-1250* and *the medieval manor and hamlet AD 1250-1450*, were studied. The first originated from largely boundary ditch fills and some occupation levels and the second from mainly yard deposits and floor levels. The most remarkable feature of the assemblage was the high incidence of gnawing marks, likely caused by carnivores, such as dogs, present at the site. A high degree of fragmentation was also observed, probably resulting from human activity. Cattle, sheep, pigs and equids were the main species found at West Cotton (Albarella and Davis, 2010). During the medieval manor period (1100-1250) the faunal assemblage was dominated by sheep (48%), followed by cattle at 26%, pig at 22% and equid at 5% (Table 1) and the later manor and hamlet phase saw an increase in sheep (62%) and equid (7%) and a decrease in cattle (20%) and pig (12%).

Table 1. Frequencies of the main domestic taxa by percentage and (MNI)

Period of occupation	Cattle	Sheep	Pig	Equid
Medieval manor (1100-1250)	26% (37)	48% (69)	22% (31)	5% (7)
Manor and hamlet (1250-1400)	20% (20)	62% (63)	12% (12)	7% (7)

Sheep bones (*Ovis aries*) were the most commonly identified species at West Cotton, hardly surprising given their importance as a food species. Indeed as Fitzherbert (1534) notes “Shepe is the mooste profytablest cattell that any man can have ...”. Goat is scarce in medieval England

and was not identified at the site. The age mortality profiles of the West Cotton sheep, as calculated by mandibular age stages (Payne, 1973), differs between the two periods. Firstly, a range of ages are represented in both the manor phase 2 and manor and hamlet phase 3, suggesting a mixed economy in which meat, milk and wool were all important. However, the kill-off pattern shows a higher proportion of the sheep were killed at a younger age in the manor phase than in the later phase. This suggests a change in the pattern of exploitation of sheep, with the production of meat being more important in the earlier period, moving toward an emphasis on wool production later (Albarella and Davis, 2010).

Calculation of the age profiles of the West Cotton cattle reveals that, in both periods, most of the animals were killed when adult or older, although some younger specimens were identified. The age mortality profile suggests that cattle were mainly used for traction, with their meat and milk being of minor importance (Albarella and Davis, 2010). This is regarded as typical of medieval sites (Grant, 1988) including the nearby sites of Burystead and Langham Road (Davis, 1992). A higher number of young cattle in the manor and hamlet period suggests a possible increase in beef production, although it should be noted the small sample size makes this a tentative conclusion. There is clear evidence for butchery on the West Cotton cattle bones (nearly 30% NISP show clear butchery marks) and the presence of all parts of the skeleton suggests that the cattle were slaughtered locally. The extraction of marrow is inferred through the identification of two metapodials which were smashed and burnt near the mid-shaft (Albarella and Davis, 2010).

The large number of immature and sub-adult pigs, consistent across both periods, identified in the faunal assemblage at West Cotton supports the use of these animals for meat and lard production. Equids are also important in the economy at West Cotton, being used mainly for traction. Indeed, the rather high percentage of equid bones in all periods seems to be a feature of the site, possibly because of light soils, which tends to suggest the exploitation of horses rather than oxen for tilling the soil. Furthermore, the number of cut marks indicative of skinning on the equid bones is higher than that found on any other medieval site (Albarella and Davis, 2010), suggesting that dead horses were exploited for their skins. This is not surprising as equid hides are known to have been used in medieval times (Grand and Delatouche, 1950; Langdon, 1989). Butchery marks are also quite common, indeed, in the later period equid becomes the taxon with the highest frequency of identified butchery, even above cattle. This suggests some exploitation of horse flesh, likely to feed hunting dogs, but also possibly for human consumption (Albarella and Davis, 2010). This is intriguing as the consumption of horse meat

is generally considered to have been widely avoided since a proscription by Pope Gregory III (AD 732). Although it is known that horse meat was fed to hunting dogs, borne out by the high numbers of gnawed bones, the similarity between the butchery patterns for the equids and other species is noteworthy. For example, a tibia from the medieval manor period was smashed and burnt near its mid-shaft, possibly to extract the marrow. This is similar to examples of marrow extraction on two cattle metapodials, and it seems unlikely marrow would be extracted to feed dogs. This indicates that horse flesh may have been consumed by the humans at West Cotton (Albarella and Davis, 2010).

The main trend seen in the faunal data is the increase in sheep and horse and decrease in cattle and pigs over time. This is thought to result from the increase in wool production and may correlate with the possible decrease in cattle age, seen in the kill-off patterns, suggesting the increase in beef production compensates for the reduction in mutton. Interestingly, there is little variation either in the animal bones between different areas of the site or across the chronological span (Albarella and Davis, 2010).

Typically, a very small number of deer were found at the site, likely because deer hunting was strictly confined to the aristocracy (Clutton-Brock, 1984; Grant, 1988). Bird bones are not common at West Cotton and were not among the primary food resources on the site. However, the stone-built manor house of the twelfth to mid-thirteenth century did have a dovecote, which would have provided a regular supply of birds for the table of the steward who probably administered the manor on behalf of his lord. Interestingly, very few fish bones were identified, those that were included freshwater fish (eel, perch and cyprinid) and sea fishes (herring and ling). While the leats, mill pond and watermill were functioning between the mid tenth to early twelfth centuries, it is likely that there would have been associated eel traps. A common Domesday reference is to watermills having both a monetary value and a value in eels, although the possible Domesday reference for the West Cotton mill only refers to a value of 12d, while the other Raunds mill, probably at nearby Mallows Cotton, was probably the larger watermill valued at 34s 8d and 100 eels.

In summary, animals were clearly highly valuable sources of food at West Cotton, providing meat, fat, milk, cheese and some eggs. They were also used for traction, aiding in the preparation of the soil for growing crops, and for their wool, hides and, probably, dung. Food production seems to derive almost entirely from domestic animals and hunting and fishing practices seem to be very minor elements of the West Cotton subsistence economy.

4. Pottery residues results and discussion

The analysis of organic residues absorbed within the fabric of ceramic vessels, using molecular and isotopic techniques, has been shown to be a powerful tool both in the investigation of past diet and subsistence practices and in the reconstruction of animal management practices (e.g. Dudd and Evershed, 1998; Copley *et al.*, 2003; Copley *et al.*, 2005a; Copley *et al.*, 2005b; Craig *et al.*, 2005; Mukherjee *et al.*, 2007; Evershed *et al.*, 2008; Outram *et al.*, 2009; Dunne *et al.*, 2012; Cramp *et al.*, 2014a; Cramp *et al.*, 2014b; Dunne *et al.*, 2016).

Here, a total of 123 potsherds from 73 reconstructed vessels were investigated according to well-established analytical procedures described in the material and methods section (Dudd and Evershed, 1998; Copley *et al.*, 2003; Correa-Ascencio and Evershed, 2014). These were selected as they were vessels for which, in most cases, full or partial profiles were available, suggesting that the potsherds were extracted from their primary deposit. Total lipid extracts (TLEs), with sufficient concentrations ($>5\mu\text{g g}^{-1}$) of lipids that can be reliably interpreted (Evershed, 2008), were recovered from *c.* 58% of the potsherds ($n=71$), although it should be noted that many of these contained very low concentrations of lipid. The mean lipid concentration of the sherds was 0.4 mg g^{-1} , with a maximum lipid concentration of 4.8 mg g^{-1} (Table 2).

The TLE's from the West Cotton assemblage were dominated by the free fatty acids (Fig. 6), palmitic ($\text{C}_{16:0}$) and stearic ($\text{C}_{18:0}$). The majority of the extracts comprise a higher abundance of the $\text{C}_{18:0}$ fatty acid than the $\text{C}_{16:0}$ component, suggestive of a degraded animal fat (Evershed *et al.*, 2002). Odd numbered fatty acids ($\text{C}_{15:0}$ and $\text{C}_{17:0}$) are also present, possibly indicative of a bacterial origin, resulting from microbial activity in the rumen, characteristic of a ruminant product origin, although no branched chain fatty acids were present.

Table 2. Sample number, vessel number and type, sherd type, date, structure, lipid concentration ($\mu\text{g g}^{-1}$), total lipid concentrations in extracts (μg), $\delta^{13}\text{C}_{16:0}$, $\delta^{13}\text{C}_{18:0}$, $\Delta^{13}\text{C}$ values,

lipid composition and classification of residues from potsherds from West Cotton, Northamptonshire

Vessel	Vessel type	Sherd type	Date	Structure	Lipid concentration	$\delta^{13}\text{C}_{16:0}$	$\delta^{13}\text{C}_{18:0}$	$\Delta^{13}\text{C}$	Classification
					($\mu\text{g g}^{-1}$)				
RP2	Shelley ware jars	Body	1100-1250	-	202	-26.6	-27.7	-1.1	Ruminant adipose
RP4	Shelley ware jars	Rim	1100-1250	Third watermill	1008	-26.9	-25.5	1.4	Porcine fat
RP6	Late Medieval Reduced ware dish	Rim	1400-1450	Tenement A	402	-27.5	-29.2	-1.7	Ruminant adipose
RP7	St Neots ware jar	Body	950-1150	w.b ditch	57	-28.9	-30.2	-1.3	Ruminant adipose
RP10	Shelley ware bowl	Body	1100-1250	-	28	-26.4	-24.9	1.5	Porcine fat
RP13	Lyveden A ware jars	Body	1150-1225	Malt House	122	-29.0	-30.1	-1.1	Ruminant adipose
RP16	Lyveden A ware jars	Body	1150-1225	Main domestic range	3474	-28.6	-30.5	-1.9	Ruminant adipose
RP22	Lyveden A ware jars	Base	1150-1225	Yard B	26	-29.4	-31.9	-2.5	Ruminant adipose
RP28	Shelley ware 'Top Hat' vessels	Base/body	1100-1250	Boundary walls A to B	269	-26.5	-28.5	-2.0	Ruminant adipose
RP30	Oolitic Coarseware jar	Base/body	950-1150	-	1840	-28.5	-32.6	-4.1	Dairy fat
RP50	Thetford ware	Body	950-1150	-	4163	-27.9	-29.2	-1.3	Ruminant adipose
RP53	Shelley ware 'Top Hat' vessels	Body	1100-1250	Building enclosure	351	-28.7	-30.1	-1.4	Ruminant adipose
RP60	Shelley ware 'Top Hat' vessels	Base	1100-1250	West boundary ditch	1194	-29.5	-33.1	-3.6	Dairy fat
RP61	Shelley ware jars	Body	1100-1250	Late Saxon domestic range	22	-28.4	-32.9	-4.5	Dairy fat
RP71	Shelley ware 'Top Hat' vessels	Base	1100-1250	Northern boundary ditch	1076	-28.5	-29.8	-1.3	Ruminant adipose
RP72	St Neots Spouted ware bowl	Rim	950-1150	n.b. ditch	3868	-28.3	-32.0	-3.7	Dairy fat
RP73	St Neots ware inturned rim bowl	Rim	950-1150	Earliest watermill	2731	-26.1	-27.8	-1.7	Ruminant adipose
RP78	Shelley ware jars	Rim	1100-1250	Third watermill	4840	-26.5	-28.7	-2.2	Ruminant adipose
RP81	St Neots ware jar	Body	950-1150	-	2033	-29.0	-30.8	-1.8	Ruminant adipose
RP82	Furnells 'Top Hat' pot	Rim	No date	-	1793	-27.7	-29.5	-1.8	Ruminant adipose
RP83	Lyveden B fish dish/dripping dish/	Rim	No date	-	1263	-26.9	-28.6	-1.7	Ruminant adipose
RP85	Furnells Lyveden A jar	Rim	No date	-	1101	-28.3	-28.4	-0.1	Mixed porcine/ruminant adipose fat
RP86	Furnells 'Top Hat' pot	Body	No date	-	428	-28.9	-32.4	-3.5	Dairy fat
RP87	Furnells Lyveden A jar	Rim	No date	-	315	-28.1	-29.9	-1.8	Ruminant adipose
RP88	Furnells Lyveden A jar	Body	No date	-	28	-26.1	-25.4	0.7	Porcine fat
RP89	Furnells Manor cooking pot	Body	No date	-	1918	-28.1	-30.5	-2.4	Ruminant adipose
RP91	Furnells site reused as griddle?	Rim	No date	-	1169	-27.4	-32.3	-4.9	Dairy fat
RP93	Late Medieval Reduced spouted bowl	Spout	1400-1450	-	3326	-28.2	-31.2	-3.0	Mixed dairy/ruminant adipose fat
RP94	Late Medieval Reduced spouted bowl	Rim/body	1400-1450	w.b. ditch	2686	-29.0	-32.7	-3.7	Dairy fat
WC30	Top Hat vessel	-	1100-1250	-	1079	-28.3	-33.5	-5.2	Dairy fat

Triacylglycerols (TAGs) and their degradation products, di- and monoacylglycerols (DAGs and MAGs), were observed in the majority of the residues (Figs. 6 and 7), with the compounds commencing from C₄₀ to C₅₄ acyl carbon atoms, with the C₅₂ the most abundant. Lower molecular weight TAGs (C₄₀ to C₄₆) which characterise dairy products were present in vessels RP22, 30, 60, 61, 72, 73, 82, 86, 91, 94 and WC30 (Fig. 7; Dudd and Evershed, 1998). Of these, 8 of the 11 vessels (RP30, 60, 61, 72, 86, 91, 94 and WC30), plot within the ruminant

dairy range, based on the carbon isotope values of the fatty acids (Fig. 8), demonstrating the usefulness of lower molecular weight TAGs as a further indicator of dairy product processing. Significantly, WC30, one of the medieval ‘top hat’ vessels from West Cotton, also comprises an abundant homologous series of short-chain fatty acids, maximising at C_{14:0}. Short-chain saturated fatty acids (C_{4:0} to C_{14:0}) typically account for up to 20% of the total fatty acid content of fresh milk (Christie, 1981; McDonald *et al.*, 1988). Interestingly, samples RP4, RP10 and RP88, attributed to a porcine product origin, display typically narrow TAG distributions (Fig. 7), maximising at C₅₂, with the C₅₀ in slightly lower abundance. In comparison, the C₄₆, C₄₈ and C₅₄ are minor components. Porcine fats bear quite distinctive TAG profiles compared with the other major domesticates, namely ovine and bovine species, due to the clear dominance of the C₅₀ and C₅₂ over the remaining saturated components (Dudd and Evershed, 1998; Mukherjee *et al.*, 2005). This gives the characteristic ‘narrow’ distribution.

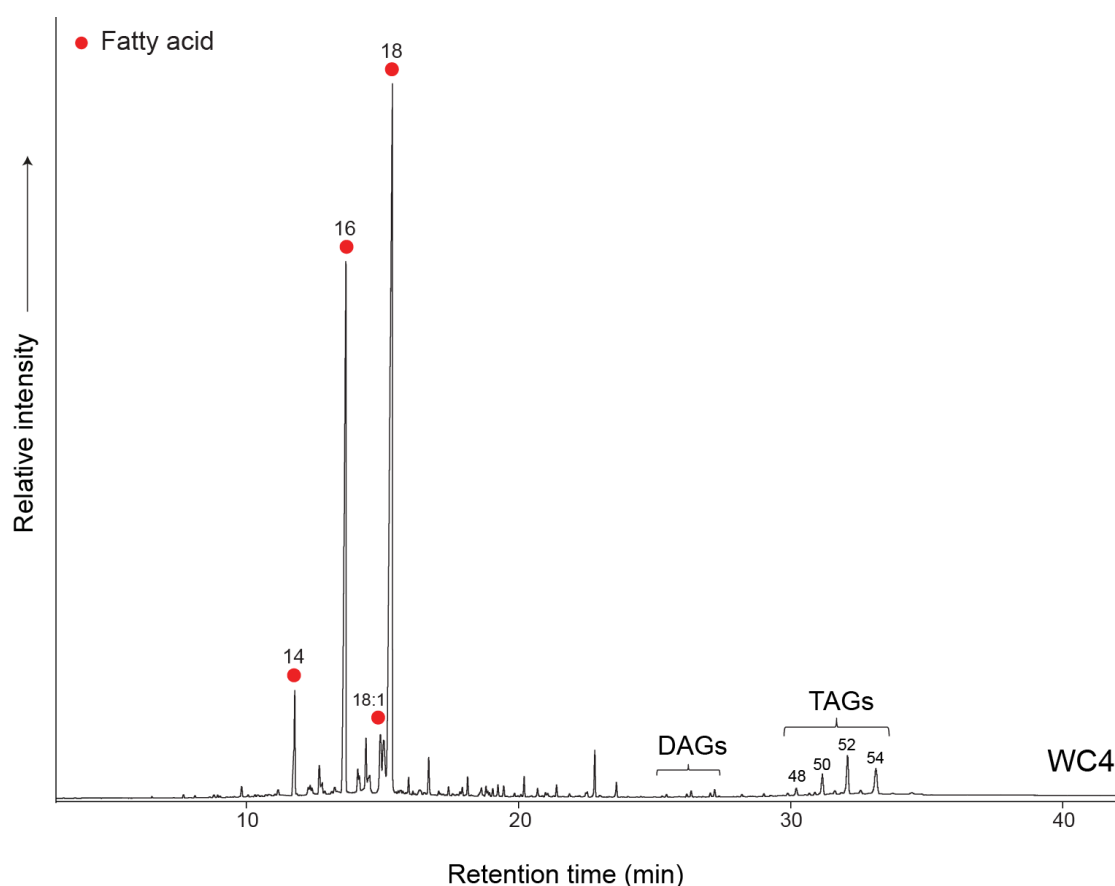


Fig. 6 Gas chromatogram of trimethylsilylated total lipid extract (TLEs) from potsherd WC4 excavated from West Cotton, Raunds, denoting the processing of animal products. Chromatographic peak identities denoted by filled circles indicating straight-chain fatty acids in the carbon chain range C_{14:0} to C_{18:0}, maximising at C_{18:0}. DAG, diacylglycerols; TAG, triacylglycerols

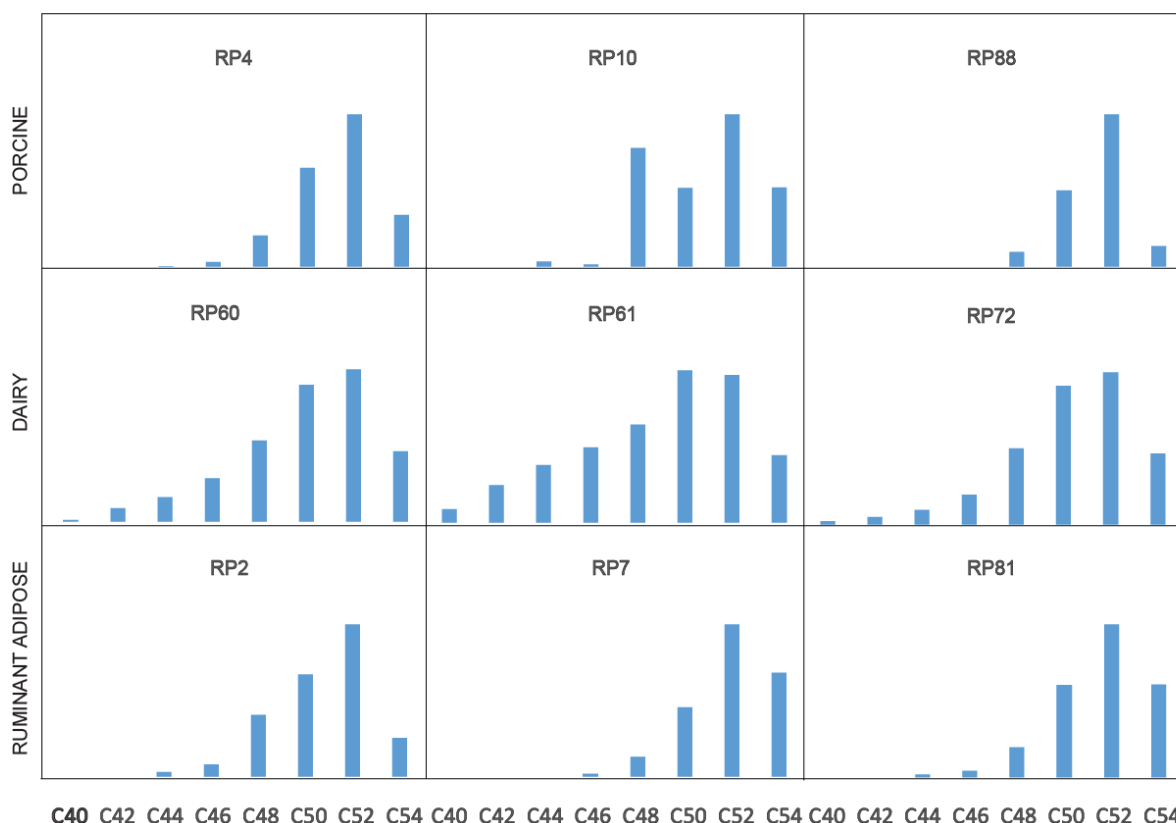


Fig. 7 Histograms showing TAG distributions present in the TLEs extracted from The West Cotton potsherds. Acyl carbon number distributions range from C₄₀ to C₅₄, usually maximising at C₅₂. Lipid profiles from RP4, RP10 and RP88 display typically narrow TAG distributions, maximising at C₅₂, with the C₅₀ in slightly lower abundance. In comparison, the C₄₆, C₄₈ and C₅₄ are minor components. This is characteristic of a porcine product origin. Lower molecular weight TAGs (C₄₀ to C₄₆) which characterise dairy products were present in vessels RP60, RP61 and RP72. The histograms are normalised to the most abundant homologue

Compound-specific carbon isotope analyses were carried out on 30 TLEs (selected on the basis of lipid abundance and interpretable profiles) to determine the $\delta^{13}\text{C}$ values of the major fatty acids, C_{16:0} and C_{18:0}, and ascertain the source of the animal products extracted from the West Cotton residues using the $\Delta^{13}\text{C}$ proxy (Fig. 8 and Table 2). The $\delta^{13}\text{C}_{16:0}$ values of the fatty acids range from -29.4 to -26.1 ‰ and the $\delta^{13}\text{C}_{18:0}$ values range from -33.5 to -24.9 ‰. The $\Delta^{13}\text{C}$ values show that eight TLEs (27%, Fig. 8 and Table 2) can be unambiguously assigned to a ruminant dairy origin, plotting within the range of ruminant dairy products, determined by analysis of modern reference dairy fats from cattle and ewes raised on a strict C₃ diet in Britain (Copley *et al.*, 2003; Dunne *et al.*, 2012). One residue, RP93, with a $\Delta^{13}\text{C}$ value of -3.0 ‰, plots close to the border between ruminant dairy and ruminant adipose values (Fig. 8). Ruminant dairy products are differentiated from ruminant adipose products when they display $\Delta^{13}\text{C}$ values of less than -3.1 ‰ (Dunne *et al.*, 2012; Salque, 2012). Archaeological animal fats which plot close to the -3.1 ‰ boundary cannot be unambiguously interpreted as ruminant dairy or adipose products due to the overlap between the observed $\Delta^{13}\text{C}$ values of ruminant

carcass and milk products in experimental work (Salque, 2012). Hence, it is likely that some mixing of dairy and adipose products occurred in this vessel. A further 17 residues (57%) plot within the range for ruminant adipose, with another 3 residues (10%) plotting in the non-ruminant/porcine range (Fig. 8). Vessel RP85 plots on the borderline between ruminant and non-ruminant/porcine adipose making attributions difficult, again suggesting some mixing of animal products (Fig. 8).

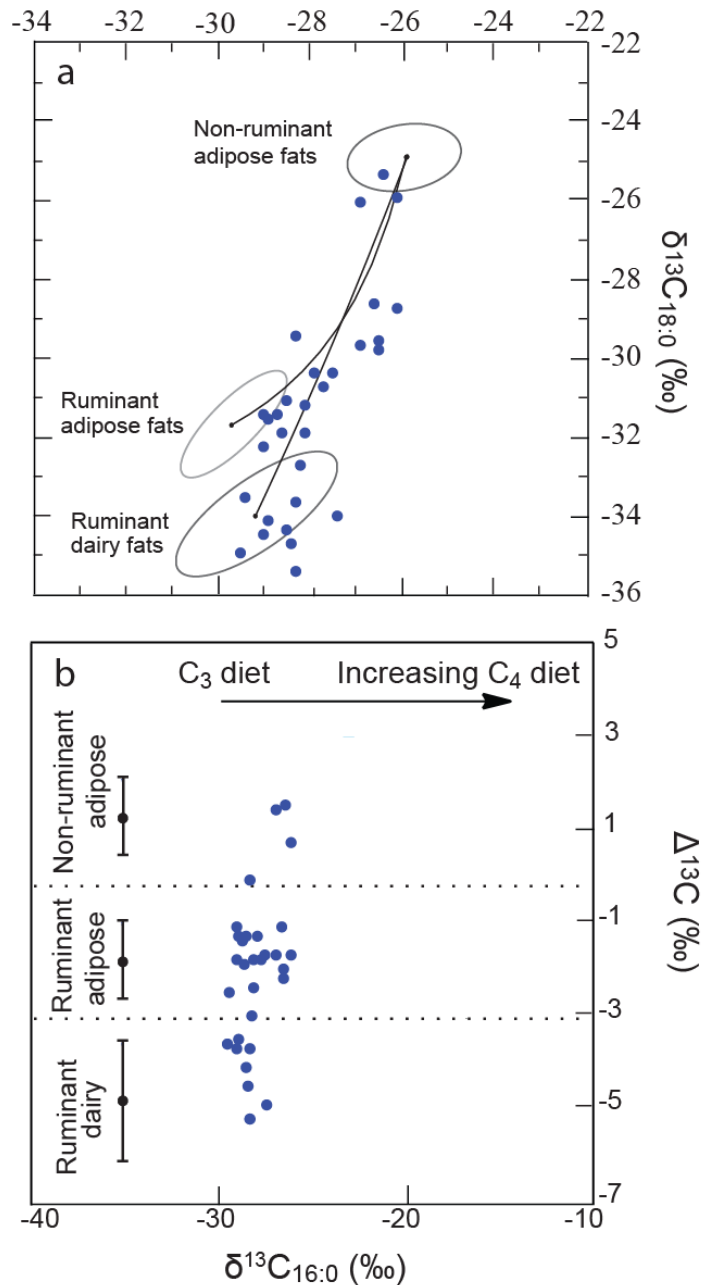


Fig. 8 Graph showing: **a.** $\delta^{13}\text{C}$ values for the $\text{C}_{16:0}$ and $\text{C}_{18:0}$ fatty acids for archaeological fats extracted from the West Cotton vessels. The three fields correspond to the $P = 0.684$ confidence ellipses for animals raised on a strict C_3 diet in Britain (Copley *et al.*, 2003). Each data point represents one potsherd. **b** shows the $\Delta^{13}\text{C}$ ($\delta^{13}\text{C}_{18:0} - \delta^{13}\text{C}_{16:0}$) values from the same potsherds.

The ranges shown here represent the mean \pm 1 s.d. of the $\Delta^{13}\text{C}$ values for a global database comprising modern reference animal fats from Africa (Dunne *et al.*, 2012), UK (animals raised on a pure C_3 diet) (Dudd and Evershed, 1998), Kazakhstan (Outram *et al.*, 2009), Switzerland (Spangenberg *et al.*, 2006) and the Near East (Gregg *et al.*, 2009), published elsewhere

4.1 Comparison of organic residues and faunal remains

Medieval faunal assemblages are rare (Albarella and Davis, 2010) thus the correlation of lipid residues and animal bones from West Cotton provided a unique opportunity to reconstruct dietary practices and animal management patterns at the site. The faunal assemblage at West Cotton was dominated by sheep in both the medieval manor period, at 48%, with an increase in the later manor and hamlet phase to 62%. It is thought a mixed economy prevailed with meat, milk and wool all being important although, in the earlier phase, the emphasis was on meat production. In the later phase, when wool production became more important, it is suggested a higher proportion of sheep were shorn of two or more fleeces before being slaughtered. The killing peak occurs in the fourth year, and not later, suggesting that the production of mutton remained important (Albarella and Davis, 2010). Indeed, Muffett (1655) notes that the best mutton is not above four years old. The age profiles of the West Cotton cattle, typical of medieval sites (Grant, 1988), suggest that cattle were mainly used for traction, with their meat and milk being of minor importance (Albarella and Davis, 2010) although, as mentioned, a higher number of young cattle in the manor and hamlet period suggests a possible increase in beef production, probably to compensate for the non-intensive production of mutton in this period. However, the clear evidence for butchery on the West Cotton cattle and sheep bones at nearly 30% for cattle and approximately 20 % for sheep, possibly suggests both were butchered in roughly similar numbers. Of course, cattle weigh much more than sheep so beef would have been eaten in much greater quantity.

Regardless of species, the correlation between the lipid residues and faunal remains demonstrated the importance of animal products (both meat and milk) within the peasant diet. Significantly, lipid residue analysis of the West Cotton pottery assemblage has demonstrated the dominance of ruminant carcass product processing at the site, in 60% of vessels, with dairy product consumption occurring in 27% of vessels. This confirms the majority of vessels were likely used as ‘stewpots’ to cook meat products and around a quarter were used to process dairy products, such as butter and cheese, sometimes referred to as ‘white meats’ of the poor, and known to have been mainstays of the medieval peasants diet (Adamson, 2004).

Both ruminant (cattle and sheep) and, less commonly, non-ruminant (pig) products were processed in jars but only ruminant products were processed in Top Hat vessels. The presence of biomarkers denoting *Brassica*, probably cabbage, and leek, in several vessels (discussed in full below), together with typical degraded animal product profiles, confirm the cooking of vegetables and carcass products to make stews and pottages. The pottages may have also comprised cereal grains although these are very difficult to identify in lipid profiles due to their low lipid content in comparison to fat-rich animal products (Hammann and Cramp, 2018). However, the presence of a bakehouse on site does suggest grain consumption took place mainly in the form of bread.

Further correlation between the faunal assemblage and lipid residue results has highlighted an interesting disparity. Pigs comprised 22% of the main domestic taxa in the medieval manor period (AD 1100-1250) and 12% in the manor and hamlet phase (AD 1250-1400), with the age curve being dominated by immature and sub-adult animals, and a few of older age presumably being kept for breeding (Albarella and Davis, 2010). This is comparable to faunal data from 87 out of 112 medieval and post-medieval sites from central England, where pig remains represent less than 20% of the total cattle, sheep/goat and pig remains (Albarella, 2006). As the optimal age for slaughter for pigs is rising two years (at which age the animals make the best pork and bacon) this suggests that pigs were an important component of the medieval peasant diet at West Cotton, for meat and/or lard production. Certainly, pig meat, in the form of bacon or salt pork, was particularly suitable for long-term preservation and, thus, very important in the peasant diet (Woolgar, 1999). However, the post-cranial bones of both caprines and pigs are very under-represented at the site and the assemblage is dominated by the much more durable teeth. In fact, the vast over-representation of pig teeth in medieval faunal assemblages is often noted (e.g. Davis, 1987; Davis, 1992; Albarella and Davis, 1994). In this instance, one outstanding characteristic of the West Cotton animal bone assemblage is the high incidence of gnawing marks, mostly caused by carnivores. Pig bones are highly porous and generally very greasy, and being mainly juvenile, would have been much preferred by dogs (Albarella and Davis, 2010). This suggests that the number of pig bones excavated may not reflect the full exploitation of pigs at West Cotton. However, this is not reflected in the lipid residue results, with only three vessels from the total assemblage (10%) being used for dedicated porcine product processing. This phenomena has been noted previously in British Neolithic Grooved Ware sites (Mukherjee *et al.*, 2008) with the percentage of pigs present at some sites being under-represented by the porcine lipid residues, although, overall, they do correlate well.

However, stable isotope analyses of pottery lipid residues may not directly correspond to the numbers of animal bones identified for several reasons, including the cooking of pigs through roasting whole carcasses on spits or because of loss through various taphonomic processes, such as gnawing by dogs. Significantly, lipid residue analysis of medieval ‘dripping’ dishes recovered from the Causeway Lane excavation, Leicester, identified non-ruminant (pig) products which derived from the fat falling from spit roasting animals, perhaps indicating that residues of porcine origin are less likely to be found in ‘cooking’ pots (Mottram *et al.*, 1999). Overall, the low lipid residue results for porcine products and the, disproportionally small, porcine faunal assemblage suggest that the consumption of pork meat and lard may be under-represented at West Cotton. There is little or no evidence for horse meat processing at West Cotton although minor amounts could have been processed in pots which were used for other purposes, producing an integrated signal that falls within the ruminant range, due to ‘masking’ by the major fat source.

Finally, FAMES from 15 samples were analysed by GC-MS in SIM mode to check for the presence of aquatic biomarkers, namely ω -(*o*-alkylphenyl) alkanolic acids (APAAs), vicinal dihydroxy acid (DHYAs) and isoprenoid fatty acids (IFAs). These are routinely used to detect marine product processing (Hansel *et al.*, 2004; Craig *et al.*, 2007; Hansel and Evershed, 2009; Cramp *et al.*, 2014b; Farrell *et al.*, 2014; Cramp *et al.*, 2015; Heron *et al.*, 2015; Gibbs *et al.*, 2017), however, no aquatic biomarkers were detected in the West Cotton pottery. This might seem surprising as fish are known to play a large part in the medieval diet, indeed, everyone was expected to fast, that is eat only fish, during Lent, on the eve of important feasts such as Christmas, and all Wednesdays, Fridays and Saturdays (Hammond, 1993). Significantly, few fish bones were identified at West Cotton, and, indeed, marine fish bones are scarce at rural settlements overall (Serjeantson and Woolgar, 2006) suggesting that fish were rarely consumed by the medieval peasant. Freshwater fish are known to have been prohibitively expensive, for example, Bishop Mitford of Salisbury paid between 4*d.* and 12*d.* for a trout in October 1406, up to twice the daily wage of a skilled craftsman (Dyer, 1998b; Woolgar, 2010). Certainly, freshwater fish were regarded as a delicacy and fishponds seem to be a feature of wealthy establishments such as monastic communities or sizeable manors (Woolgar, 1999). However, it should be noted that herring, the main fish eaten by the medieval peasant, were not prepared by boiling in pots, so may have been cooked in other ways that leave no trace or were brought to the site already smoked or salted.

4.2 Leafy vegetable processing

Significantly, lipid profiles extracted from several sherds (e.g. RP5, RP17, RP25, RP35, RP36, RP38 and RP45; Fig. 9) revealed a mixture of compounds that included three major components: nonacosane, nonacosane-15-one and nonacosan-15-ol, which together comprised more than 70% of the volatile constituents of the organic extract from the sherds (Evershed *et al.*, 1991). These are long-chain aliphatic compounds widely present in nature as constituents of epicuticular leaf waxes of higher plants (Kolattukudy *et al.*, 1976), known to protect the plant from bacterial and fungal pathogens and decrease moisture loss. The epicuticular leaf wax of *Brassica oleracea* (cabbage) is known to consist predominantly of *n*-nonacosane and its oxygenated derivatives, nonacosan-15-one and nonacosan-15-ol (Purdy and Truter, 1963; Netting and Macey, 1971). GC and GC-MS analysis of fresh epicuticular leaf wax of *B. oleracea* confirmed the presence of these long-chain alkyl compounds and $\delta^{13}\text{C}$ values of the archaeological *n*-nonacosane and nonacosane-15-one (Fig. 9, RP5; -35.6 ‰ and -35.0 ‰, respectively) correlate well with the values of modern *Brassica* leaves which were -35.4 ‰ and -35.8 ‰, respectively (Evershed *et al.*, 1994). The earliest records of cultivated cabbages are found in ancient Greek and Roman sources, and date from *c.* 600 BC. Today, there are more than 200 cultivated varieties of *B. oleracea*, including cabbage, cauliflower, kale, broccoli, savoy and Brussel sprouts (Brouk, 1985). Comparison to modern varieties of *B. oleracea* shows that the distribution of lipid components found in the West Cotton vessels best fits that of cabbage although turnip (*B. rapa*), which was also cultivated during the late Saxon period, is also a possibility. Analysis of the epicuticular leaf wax of the mature leaves of a modern cultivar found a distribution of components very similar to that of *B. oleracea* although lipid distributions in juvenile turnip leaves comprise predominantly free fatty carboxylic acids.

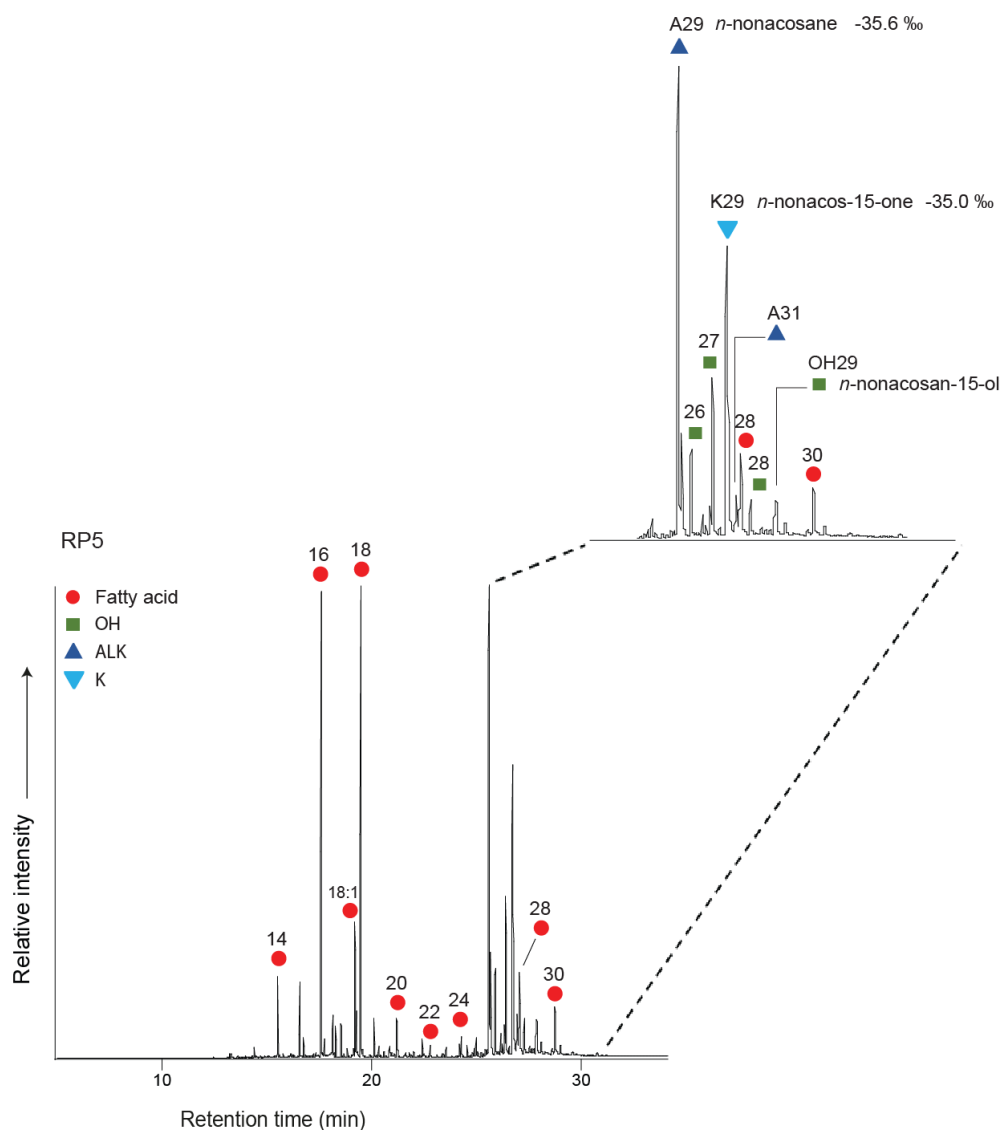


Fig. 9 Partial gas chromatogram of trimethylsilylated total lipid extracts (TLEs) from potsherd RP5 excavated from West Cotton, Raunds, denoting the processing of leafy vegetables. Chromatographic peak identities denoted by filled triangles comprise *n*-alkanes in the carbon chain range C_{29:0} to C_{31:0}, filled circles indicating straight-chain fatty acids in the carbon chain range C_{14:0} to C_{30:0}, maximising at C_{18:0}, filled squares indicating long-chain *n*-alcohols in the carbon chain range C_{26:0} to C_{29:0} and inverted triangle denoting the ketone K₂₉. IS, internal standard, C₃₄ *n*-tetratriacontane

The clear inference from this data is that the potsherds containing these waxy components are derived from vessels that have been used in the preparation (e.g. cooking) of a Brassica vegetable. Interestingly, these waxy components were also identified in more complex lipid profiles, including fatty acids, and mono-, di- and triacylglycerols, from some of the other vessels sampled (Evershed *et al.*, 1991). These lipids denote a typical degraded animal products profile, suggesting that the cabbage was cooked with carcass fats, possibly as part of a stew.

Additional evidence for the processing of leafy vegetables comes from the identification of the C₃₁ ketone (hentriacontane-16-one) and the C₃₁ *n*-alkane (hentriacontane) in several of the West Cotton vessels, including Lyveden A ware jars, RP25 and RP38, and Shelly ware jars, RP35 and RP36. These components are characteristic of the epicuticular leaf wax of modern leek, *Allium porrum*, (Evershed *et al.*, 1992; Evershed *et al.*, 1995; Raven, 1995; Raven *et al.*, 1997).

Interestingly, a striking feature of the archaeobotanical assemblage from West Cotton was the large number of *Brassica* spp. (cabbage, mustard etc) seeds recovered from the three malt houses, attached to tenements A, B and C, constructed around the middle of the thirteenth century (Campbell and Robinson, 2010; Chapman, 2010). These could not conclusively be identified to species but, during the medieval period, mustard seed was used in ale to reduce fermentation (Man and Weir, 1988). Alternatively, the abundance of *Brassica* spp. seed in the malt house samples may be because it grew as a major contaminant of the cereal crops.

The identification of lipid biomarkers denoting *Brassica* processing, the abundance of *Brassica* spp. in the malt houses and their sporadic occurrence in earlier deposits suggests that *Brassica* species were cultivated both for their seeds and leaves from the twelfth century onwards.

Lipid profiles from three vessels, RP4, RP6 and RP89, included mid-chain ketones (C_{31:0}, C_{33:0} and C_{35:0}). Experimental work has shown these ketones, present in a monomodal distribution, originate from the pyrolysis of acyl lipids via ketonic decarboxylation reactions, which occur in unglazed ceramic vessels during cooking when the temperature exceeds 300° C. These ketones are thought to accumulate gradually with repeated use (Evershed *et al.*, 1995; Raven *et al.*, 1997), suggesting that these vessels were regularly used to cook foods at high temperatures. This correlates with extensive evidence of sooting and blackened patches found on many of the vessels.

In summary, pottery would likely have played an important role in medieval cooking as it was able to both bear, and retain, sustained heat for prolonged periods. This would have allowed the slow cooking of the stews and potages, suggested by documentary evidence, and confirmed in this study, to be the mainstay of the medieval peasant diet. Of course, the higher social classes would have kitchens with more sophisticated kitchen equipment, and a wider range of pottery vessels, making a more diverse menu possible (Dyer, 1994; Adamson, 2004), although the peasant also likely owned some metal pots as part of their available cooking utensils. Thus, for the medieval peasant, the main cooking facility would have been the stewpot, which was

probably set in hot ashes adjacent to the fire rather than suspended above it. At West Cotton, all the better-preserved central hearths in the kitchens comprised a heavily burnt stone slab, where the fire had been set, flanked by areas of pitched small stones and pottery sherds, less heavily burnt, where the pot or pots may have stood (Fig. 10, showing a typical hearth setting).



Fig. 10 Structure of typical West Cotton hearth, with a central hearth stone partially surrounded by a surface of pitched stone often including pottery sherds

5. Conclusion

It is notable that five seasons of excavation (during the 1980s) at the small deserted medieval hamlet at West Cotton, Raunds, together with four and a half years of post-excavation analysis, revealed the dynamic processes of constant development in a manner rarely achieved at other comparable sites in England. Its origins lie in a mid-tenth century Saxon settlement, based on one-acre plots, comprising a timber hall with ancillary buildings and an adjacent watermill. A small Norman manor house was built in stone in the twelfth century and probably relocated in the thirteenth century. The final form of the site, in the fourteenth to mid-fifteenth century, was as a hamlet of peasant tenements. The synthesis of these structural archaeological remains, in combination with substantial artefact and faunal assemblages and considerable environmental investigation (Campbell and Robinson, 2010), made a major contribution to medieval settlement studies, and, on a broader scale, helped progress our understanding of the origin of the English village.

West Cotton also provided the largest (107643 sherds of pottery, 823.5kg) Anglo-Saxon and medieval ceramic assemblage from a rural context in Northamptonshire. Significantly, the site

yielded a remarkable assemblage of reconstructed pots. These seventy-three vessels had, in most cases, full or partial profiles, suggesting that the potsherds were extracted from their primary deposit. At the time of excavation, some thirty years ago, organic residue analysis was in its infancy, with many of the, now routine, analytical technologies and approaches still to be established. Consequently, the assemblage provided a unique opportunity to investigate both the commodities processed in the vessels and also address questions of vessel use (Dunne *et al.* In prep). Nonetheless, despite the significant number of research articles arising from the West Cotton project (Evershed *et al.*, 1991; Charters *et al.*, 1993; Evershed *et al.*, 1995; Charters *et al.*, 1997), the full results from lipid residue analyses of the pottery assemblage have never been published. However, the publication of the site monograph in 2010 (*West Cotton, Raunds. A study of medieval settlement dynamics AD 450-1450. Excavation of a deserted medieval hamlet in Northamptonshire 1985-89*) laid the groundwork for this full re-evaluation of the lipid data, in conjunction with interpretations made by the pottery and faunal specialists and documentary sources. This has also allowed us to incorporate analytical methodologies developed relatively recently, for example, the use of GC-MS in SIM mode (selected ion monitoring) to identify aquatic biomarkers.

In summary, lipid residue analysis of the West Cotton pottery assemblage confirmed the dominance of ruminant carcass product processing at the site, in c. 60% of vessels, with around one quarter of vessels being used to process solely dairy products such as butter and cheese, sometimes referred to as ‘white meats’ of the poor, and known to have been one of the mainstays of the medieval peasants diet (Black, 2003; Adamson, 2004). Diagnostic biomarkers which suggested the processing of leafy vegetables, such as cabbage and leek, in vessels also containing typical degraded animal products profiles, suggests that these were cooked with carcass fats, possibly as part of a stew. This confirms pottery would likely have played an important role in medieval cooking, allowing the slow cooking of the stews and potages, suggested by documentary evidence to be the mainstay of the medieval peasant diet. The association between cabbage and stewed meat is particularly noteworthy as there are few references in other sources for peasant culinary practice and a stew of this type was not to be found in high status kitchens. Some evidence of porcine product processing was found, but, interestingly, it seems that fish did not feature significantly in the medieval peasant diet.

The correlation of lipid residues with the animal bones from West Cotton also provided a unique opportunity to reconstruct dietary practices and animal management patterns at the site.

Together, the combination of lipid residues, and faunal and documentary evidence has confirmed the importance of meat, dairy and vegetables in the diet of the medieval peasant.

In conclusion, this synthesis of lipid residue analyses with documentary sources, faunal and archaeobotanical assemblages and other information gained from archaeological excavations, for the first time, has provided major insights on the everyday diet of the medieval rural peasant and helped illustrate agricultural production and consumption at one of England's early villages.

Acknowledgements

This work is testament to the many PhD students and post-doctoral researchers who, over several decades, have contributed to the development of the technique of organic residue analysis, particularly the contributions of Stephanie Charters and Stephanie Dudd. We also thank all the dedicated archaeologists who worked on the Raunds Project.

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Material and methods

The pottery investigated in this study comprises a group of ‘reconstructed’ vessels from West Cotton. These are vessels for which, in most cases, full or partial profiles were available, suggesting that the potsherds were extracted from their primary deposit. Of the 73 vessels analysed, 22% were sampled at three points from the profile, rim, body and base and a further 21% were sampled from the body and rim. The remainder (58%) were mostly bowls and were only sampled from the body.

Lipid analysis and interpretations were performed using established protocols described in detail in earlier publications (Charters *et al.*, 1993; Dudd and Evershed, 1998; Copley *et al.*, 2003). Briefly, ~2 g of potsherd were sampled and surfaces cleaned with a modelling drill to remove any exogenous lipids. The sherds were then ground to a powder, an internal standard added and solvent extracted by ultrasonication (chloroform/methanol 2:1 v/v, 30 min, 2x10ml). The solvent was evaporated under a gentle stream of nitrogen to obtain the total lipid extract (TLE). Aliquots of the TLE were trimethylsilylated (*N,O*-bis(trimethylsilyl)trifluoroacetamide 20 µL, 70° C, 60 min), and submitted to analysis by GC and GC/MS.

Further aliquots of the TLE were treated with NaOH/H₂O (9:1 w/v) in methanol (5% v/v, 70°C, 1 h). Following neutralization, lipids were extracted into chloroform and the excess solvent evaporated under a gentle stream of nitrogen. Fatty acid methyl esters (FAMEs) were prepared by reaction with BF₃-methanol (14% w/v, 70°C, 1 h). The FAMEs were extracted with chloroform and the solvent removed under nitrogen. The FAMEs were re-dissolved into hexane for analysis by GC and GC-C-IRMS.

GC analyses were performed on a Hewlett-Packard 5890A gas chromatograph, coupled to an Opus V PC using HP Chemstation software which provided instrument control, data acquisition and post-run data-processing facilities. Samples were introduced by on-column injection into a 60 cm x 0.53 mm (i.d.) retention gap (deactivated polyimide clad fused-silica capillary; Phase Separations, U.K.) connected to the analytical column via a lightweight glass-lined stainless-steel union of 0.8 mm i.d. (S.G.E.). the column used was a polyimide clad 12 m

x 0.22 mm i.d. fused-silica capillary, coated with BP-1 stationary phase (immobilised dimethyl polysiloxane, OV-1 equivalent, 0.1 μm film thickness; S.G.E.). The carrier gas was helium and the temperature programme comprised a 2 min 50°C isothermal hold followed by an increase to 350° at a rate of 10° min^{-1} followed by a 10 min isothermal hold. A procedural blank (no sample) was prepared and analysed alongside every batch of samples.

GC/MS analyses were performed using a Finnigan 4500 quadrupole mass spectrometer (Finnigan MAT GmbH, Bremen, Germany) directly coupled to a Carlo Erba 5160 Mega series GC with on-column injection. Operating conditions were as follows: ion source, 170°C; emission current, 400 μA and electron energy, 70 eV. The GC-MS interface was maintained at a temperature of 350°C. Spectra were recorded over the range m/z 50-850 every 1.5 s. Data were acquired and processed using an INCOS data system.

Carbon isotope analyses by GC-C-IRMS were carried out using a Varian 3500 gas chromatograph (Varian Associates Inc., Walnut Creek, CA) attached to a Finnigan MAT Delta-S isotope ratio mass spectrometer (Finnigan MAT GmbH, Bremen, Germany) *via* a modified Finnigan MAT combustion interface. The GC column used was a 25 m x 0.32 mm i.d. polyimide-clad fused silica capillary column coated with HP5 (5% diphenylpolysiloxane 95% dimethylpolysiloxane) stationary phase of film thickness 0.33 μm . Helium was used as carrier gas and the samples were dissolved in an appropriate volume of hexane. The reactor temperature was 860°C, and the mass spectrometer source pressure was 9×10^{-5} Pa. Gas chromatography temperature programming was from 70 to 150°C at 10°C min^{-1} , and then from 150 to 290°C at 5°C min^{-1} following a 2 min isothermal hold at 70°C after injection. At the end of the temperature programme the gas chromatograph oven was kept at 290°C for 5 mins. Samples were injected in the splitless mode at an injector temperature of 290°C. Carbon isotope ratios were expressed relative to VPDB.

(Salque, 2012)

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